

## **METHOD AND APPARATUS FOR BATTERY RECONFIGURATION FOR RADIO CONTROL APPLICATION**

### **Field of the invention:**

- 5      The present invention relates to how a battery system powers both the electronics and a motor to propel a vehicle. More particularly, this invention pertains to the method and apparatus for connecting various numbers of battery cells to the battery system to optimize its performance according to the user's present needs.

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### **Background:**

- Radio control (r/c) cars, boats, airplanes, submarines, etc. all have electric motors to make them move or support their movement. The more battery cells that are connected in a series configuration, the more voltage and/or speed that can be delivered to the vehicle. Connecting more battery cells in a parallel configuration allows more amperes and power to be delivered to the vehicle. A combination of series and parallel connections of the battery cells allows the user to configure an optimum power system for a vehicle in terms of weight, size, and the duration that the motor can be activated.
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- 20     Since the commercialization of miniature vacuum tubes in the 1950s, hobbyists have tried to make model airplanes, boats, and cars function under remote user control by the activation of switches and knobs to control the direction and rate of speed of the model. The early r/c hobbyists all used glow fuel engines to power the vehicles because electric motors were too heavy, slow, and expensive to consider as the primary propulsion device. Batteries located in the vehicles powered electronic modules which converted radio frequency (rf) signals from the user's transmitter into specialized control signals. These signals were sent to a servo unit which turned front wheels on cars, or elevator and rudder surfaces on planes, or tillers and rudders on boats.
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- As battery and motor technology advanced, the r/c hobbyist could eliminate the noisy, fuel-driven engine and employ quiet electric motors to propel the vehicle. With the invention of the transistor and integrated circuits, the hobbyist could use a single set of batteries to power all the electrical circuits on a vehicle. This means that the receiver, motor speed control, servos, and drive motor all shared the same battery power source. This greatly reduced the weight of the model and simplified the number of parts a hobbyist had to buy to create a remote controlled vehicle.
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Advances in electronics miniaturization and foam material processing have permitted the cost of r/c models to drop significantly. It is quite typical for a model r/c airplane flyer to have 4 to 10 fully assembled planes at the airfield during a session. Similarly, electric model car enthusiasts typically have several cars available to enter various types of races – one for each type of racing class. The same is true for boating

40 enthusiasts. Wind sailboats, “cigar-boat” racers, and hydroplanes are available as needed for the different types of racing. All of these vehicles need a battery system. Typically a separate battery is needed for each device to match the size, weight, and power requirements of the specific vehicle in which it is used.

Especially in the low-cost foam airplanes that currently exist in the r/c hobby field, the cost of batteries for each model is now equal or greater than the cost of the model’s electronics. The present invention

45 describes a method and an apparatus for quickly configuring battery cells so that they can be moved from system to system with a minimum of difficulty, and thus lowers the cost of operation of multiple vehicles.

#### SUMMARY OF THE INVENTION

50 According to one aspect of the invention, a battery system is created for r/c model vehicles that permit the rapid reconfiguration of battery cells to connect to many different vehicle systems with various serial and parallel configurations.

55 Other features and advantages of the present invention will become apparent from the accompanying drawings, and from the detailed description, which follows below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention are illustrated by way of example and not intended to be limited by the figures of the accompanying drawings, in which like references indicate similar elements

5 and in which:

Fig. 1 depicts an exemplary r/c model airplane electrical wiring to demonstrate the electrical components in a brushed model airplane in accordance with prior art. The ESC is an Electronic Speed Controller that provides power to the receiver (Rx) and to the motor once the Rx gives back a signal to the ESC telling

10 what average current to apply to the motor. The servos obtain their power from the Rx to drive their internal motors and gearboxes to the desired position.

Fig. 2A depicts a 6 cell NiMh configuration that is the current state of the art. It has been configured as in a plane of four adjacent cells on the bottom row and then two additional cells are placed in mirror image on

15 the next row. The choice of the JST connector is a typical example of what a 6-cell r/c model airplane would use. Any of the other standard connectors (Dean’s, Tamiya, Anderson Pole, AstroFlight ZeroLoss,

etc.) could also be used. All r/c battery packs are either covered with tape or shrouded by heat-shrink plastic to ensure that the wires connecting the individual cells are not exposed. This is also necessary to give physical strength to the battery system so they do not disassemble in a crash.

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**Fig. 2B** depicts a 2 cell NiMh configuration that is used to extend the 6 cell battery subsystem shown in Fig. 2A. The connector 201 from the 6 cell subsystem mates with a matching connector 202 in the 2 cell subsystem to extend the serial connections so that now 8 cells deliver their final voltage to the output connector 203.

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**Fig. 2C** depicts the combined subsystems of Fig. 2A and Fig. 2B having more available voltage. The output connector 203 can either match the type used in Fig. 2A so that is used in the same r/c vehicle as Fig. 2A, or it can be a different standard connector that would be employed in a different r/c vehicle. Fig. 2C depicts the battery cells as rectangular boxes for ease of drawing. When heat-shrink wrapping is applied, the combined battery cells more closely resemble rounded-edge boxes than individual cylinders. The two mating connectors 201 and 202 are a matched male-female set. It is typical for the battery to have the female connector to minimize the possibility of electrical shorting when disconnected.

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**Fig. 3** depicts three different configurations of the 8 cell battery system comprised of a 6 cell and a 2 cell “add-on” subsystem. The three different orientations of the 2 cell “add-on” subsystem permit the battery to be used when physical dimensions and balance point requirements change from r/c model to model.

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**Fig. 4** depicts a “2s3p” battery system configuration along with a switch box electrical interface and battery charger. The electrical interface allows the individual cells to be discharged and/or recharged independently.

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**Fig. 5** depicts a “2s3p” battery system configuration along with an embedded processor to minimize the number of individual wires going from the electrical interface to the battery system.

## DETAILED DESCRIPTION

According to the embodiments described herein, a method and apparatus are described in which a plurality of r/c model vehicles can be powered by a single battery system. The battery system allows different number of serial and parallel cells to be quickly reconfigured to match the voltage and power requirements of the vehicle.

Battery cells currently come in four generic classes: Alkaline, Nickel-Cadmium (NiCd), Nickel-Metal-Hydride (NiMh), and Lithium. Additional classes (like zinc-air) will be added in the future for hobbyist uses. The Alkaline (which is the common household flashlight battery type) produces 1.5 volts nominally when new. It is rarely used in the hobbyist market because it is typically not rechargeable and thus very expensive to employ on a long-term basis. Both the NiCd and NiMh produce 1.2 volts per cell and are the dominant types today in the r/c market. They are rechargeable and can typically be re-used 200-500 times before they need to be replaced. They have a very low cost of long-term operation. Lithium (both the metal-ion type and the polymer type cells) produce 3.7 volts per cell and are quickly becoming the battery of choice for small airplanes, boats, and helicopters because it has a great weight to power ratio. This provides long vehicle operation duration. They are rechargeable approximately 200-300 times before needing replacement and the Lithium cells are currently about 50% more expensive than their equivalent power NiCd cells. However, the Lithium polymer cells typically weigh  $\frac{1}{2}$  to  $\frac{1}{3}$  as much as their NiCd counterparts and thus are very desirable in aircraft and water vehicles where reduced weight has high value.

Battery cells are typically connected in series to provide an operating voltage range between 4 to 30 volts. Most brushed electric motors used for propulsion operate with a range of 6.0 to 10.0 volts. Most r/c electronics systems can operate anywhere in the 3.7 to 12 volt range. Highly efficient "brushless" motors for propulsion typically need higher voltages (9 to 30 volts). Fig.1 shows schematically how a typical brushed r/c model airplane would be configured for a battery system that provides 6 cells of NiMh. The 6 cells provide 7.2 volts to an Electronic Speed Controller (ESC) which provides a regulated voltage to the r/c receiver (Rx) which in turn provides pulsed voltages to the servos that control the elevator and rudder. The ESC provides pulsed voltages from the battery to the motor according to the Rx signals which are controlled through the pilot's transmitter. The motor draws the most power from the battery system and must be "shut down" when the battery system voltage drops to a pre-determined cut-off voltage. This is required so that if the pilot does not land the plane before the battery system voltage goes too low, that the propulsion motor will turn off but that the servos still have enough power to land the plane safely.

35 For most r/c racing hobbyists, motors are a type of consumable that are given excessive voltages so that  
they produce maximum power for short periods of time. It is a common practice in model r/c car racing to  
replace a vehicle's motor every two races because excessive current has burned the brushes and melted the  
internal wires. This excessive current is often the deciding factor in whether a car wins or not. The motor  
typically costs less than a battery system. Racers often "add" one or more additional battery cells in series  
40 to the standard battery configuration to gain additional power for a race. In a standard 6 cell r/c racing car  
configuration, a driver might have a 6 cell battery pack for practicing, a 7 cell pack for hard driving to  
refine his driving technique during racing, an 8 cell pack for typical racing conditions, and a 9 cell pack to  
use only when the final race for the championship is at stake. Each battery pack is hard wired to have the  
full complement of cells, and has a special connector which mates with the connector on the ESC. A racer  
45 often has more money expended in a set of batteries than in the racing vehicle itself. The financial  
difficulty becomes even more pronounced if the racer has three or four different cars that are entered in  
different events during the day. Each car system needs its own set of batteries for each event.

50 The same plurality of battery cells exists for r/c boaters, airplane pilots, and helicopter operators. In the r/c  
flying models, the owner oftentimes has to add additional battery systems in parallel to the standard  
configuration of series connected batteries in order to increase the total power available to the system. This  
is known as an "XsYp" system where X is the number of cells connected in series and Y is the number of  
"series" configured sets that are finally connected in parallel to give additional power. The need for the  
55 "XserialYparallel" system exists because battery cells often come in very small packages. Ideally, huge  
battery cells should exist so that a single series connected battery system is sufficient. However, motorized  
gliders often need 30 to 50 battery cells wired in an "XsYp" manner to produce the required power for  
racing events. Such battery systems can cost many hundreds of dollars to configure. And multiple systems  
may be needed with increased serial cell counts to produce the excessive voltages needed to win races.

60 **Fig. 2A** shows a battery system with six cells 200 connected in series which terminate to a standard  
connector 201. This is the current state of the art where each of the cells 200 are soldered in a positive to  
negative daisy-chain manner to increase the voltage, and the output is available at 201 to connect to an ESC  
which will power the electronics and drive a motor. **Fig. 2B** shows an additional two cells with a connector  
65 202 that mates with the six cell system in **Fig. 2A** 201. The connector 203 is the final output of combining  
the six cell with the two cell subsystem to produce an eight cell system **Fig. 2C**. The battery system in **Fig.**  
**2C** can be used in the same airplane, car, boat, or helicopter as shown in **Fig. 2A** but now produces more  
power, because of increased voltage, to provide increased performance and win races. There are many r/c  
devices which only accept six cell systems, and have a special connector 201 which is required to mate  
with the ESC. In a different airplane, car, boat, or helicopter, an eight cell system may be required. These  
70 vehicles typically require a larger capacity connector 203 needed to carry the larger amperage and voltage.  
In its simplest form, the current invention allows a single battery cell system to be used in either r/c

configuration without requiring two separate battery systems for each configuration. One unique advantage of the current invention is that the specialized connectors needed to connect to either an ESC or a motor are integrally part of the design. Connectors are typically of the JST type or the Dean's Ultra connectors which

75 handle relatively large current flows without heating, have a high resistance to vibrating free during normal operation, and permit the battery systems to be thrown free from a crash of an airplane or rollover of a car. This last feature is essential to stop a propeller from spinning or wheels from rotating so fast that the vehicle motor is destroyed during a mishap.

80 A second advantage of the current invention is that the wires connecting the six cell to the two cell subsystem allows the final battery configuration to be adjusted in physical layout to match the physical constraints of the model into which the battery system is placed. **Fig. 3** illustrates three different configurations of the **Fig. 2C** system. Configuration 300 shows the additional two cells stacked in the “void” of the **Fig. 2A** system. This new configuration is often called a “brick” pattern and readily fits into the fuselage and sponsons of most airplanes and boats, respectively. The configuration 301 has the two addition cells oriented to fit behind the six cell set. Such a configuration might be needed in very narrow portions of the fuselage, or when the balance of the airplane or boat needs the batteries distributed over a longer axis. Configuration 302 has the two additional cells stacked upon the thick portion of **Fig. 2A** battery cells. This configuration is often needed in airplane and helicopter models where the balance point

85 of the vehicle is needed as far forward inside the model as possible. The current invention allows the battery configurations to be adjusted to meet space and balance point requirements for each system into which the cells are installed. Standard battery systems are rigidly held together with tape or heat-shrink tubing and cannot be reconfigured to take new shapes.

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95 A third advantage of the current invention is that repairs of worn-out or damaged battery subsystems are easier to effect. When a battery pack begins to fail to hold a useful charge, typically one or two batteries are defective and the rest of the system cells have 30-40% of their battery life still available. The current invention allows a user to measure the voltages and currents present in both the **Fig. 2A** part of the system separately from the **Fig. 2B** part of the system. Whichever subsystem is failing can be repaired much easier

100 than traditional r/c battery system where all the cells must be dismantled to perform the tests. This is especially true when there are parallel subsystems involved as will be described next.

105 **Fig. 4** shows a 2s3p system where each subsystem has two serial cells connected together and then three of these subsystems are connected in parallel to form the final battery system. Each of the 2s (two serial) subsystems are identical and have a connector that would allow that subsystem to be used in a vehicle that only needs two serial cells to be functional. By connecting the three subsystems 400, 401, 402 in parallel, they triple the amount of current that the system can deliver to the model. Large electric-powered glider aircraft often have 10s15p NiMh battery cells needed to provide several hundred amperes of sustained

power for twenty minutes of motor duration. There are no NiMh cells currently large enough to provide  
110 the large current drain, and so a large number of parallel subsystems are needed. Another reason for the parallel subsystems is to allow various packing configurations to fit in the tapering cross-section of the glider's fuselage. The current invention allows all of the parallel subsystems to be identical, and to be used in other aircraft with the proper connector installed. The added advantage is that if one parallel subsystem fails, the replacement of that subsystem is far less expensive than replacing the entire system. Bad crashes  
115 in r/c airplanes and cars often destroy only a few batteries located in the immediate impact location. The other batteries usually survive. The current invention allows only a minimal number of subsystems to be replaced or repaired.

Batteries have a specific voltage for each cell type: 1.2 volts for NiCd and NiMh, and 3.7 volts for Lithium.  
120 When they are configured in series and parallel systems, problems can arise when they are charged as a group rather than each cell individually. During battery discharge, certain cells will discharge more quickly than others. After many charge-discharge cycles in the vehicle, the battery system can have certain cells that do not get fully recharged because the adjacent cells in the series charge (and discharge) more quickly than others, and cause the charging process to terminate early. This results in some of the series connected  
125 cells not having the same voltage and current storage capacity compared to other sets used in a parallel configuration. In the literature this is known as "battery reversal" and "battery memory effect problems". This typically appears only after 5 or more charge-discharge cycles, or when eight or more cells are connected in series. This can be a serious problem for battery systems used in racing conditions because the reduced power from certain serially connected cells can easily mean the difference between finishing  
130 first or finishing third in a race. Over a long period of time, this can render some battery systems unusable.

A modification of the wiring shown in Fig. 2C, which is shown in Fig. 4, permits each cell to be charged independently without disassembling the entire battery system. The wires 403 are connected to each cell's positive terminal. The standard group wires 404 and 405, plus the individual 403 wires, permit any single  
135 cell to be charged independently of any other cell. Very small wires can be used for the individual 403 wires since they will carry very small current loads. Every 5<sup>th</sup> to 10<sup>th</sup> charging cycle, a special cable is connected to the battery subsystem which makes use of the individual 403 wires in conjunction with the larger 404 and 405 wires. The battery is first discharged and then re-charged at 1/20 of its specified current capacity. This process typically takes 20 hours and can be accomplished during a day when the vehicle is  
140 not being used. The same wiring process that makes up the Fig. 2A and Fig. 2B processes would be used to insure that the individual cell charging feature also has the "XsYp" capabilities of the current invention.

The special cable connects to an electrical interface 406 that uses mechanical relays or electrical switches  
145 407 to connect each cell to the battery charger 408 one at a time to perform the standard discharge followed by the standard charge operation. Once the first individual cell is cycled, the electrical interface then

advances to the next battery cell and the process is repeated. This continues until all cells have been independently cycled to bring them up to their full capacity. Special circuitry in the electrical interface box can record the discharge and charge amounts for each cell and display them to the user. Cells that are seriously low in capacity can be identified through this process and replaced. The interface can also  
150 identify when a significant number of the individual cells are so reduced in charge capacity that the entire subsystem should be replaced.

The wiring interface for **Fig. 4** can either be part of the connector system used to carry the 404 and 405 large capacity wires, or they can be independent connectors that have a small unique connector attached to  
155 the covering of either the **Fig 2A** for **Fig. 2B** subsystem. This later connector then attaches to the individual 403 wires and can be very light weight. In this configuration, no wires need to extend beyond the battery subsystem outer shell. This reduces system cost and complexity.

**Fig. 5** shows a variation on the individual wiring of cells depicted in **Fig. 4**. In this case, an integrated  
160 circuit 510, with an embedded microprocessor and a series of matrix configured FET switches, is attached inside each battery system. A single control line 511 detects a serial coded pulse message from the electronic interface 506 that is attached to the battery charger 408. The programmed message from the serial electronics communication chip 509 tells the integrated circuit inside the battery subsystem which set of FET switches to turn on so that a specific battery cell is either discharged or charged. When the battery  
165 charger tells the electronic interface that the operation is complete for that individual cell, the electronic interface sends a new pulse-coded message to the integrated circuit 510 to open the previous set of FET switches and now close a new set corresponding to the next battery cell to be processed. This process would continue until all cells are discharged and then recharged to their full capacity. The advantages of the method in **Fig. 5** are that a total of only three wires (404,405,503) need to go from the electronic  
170 interface to the battery system. This reduces weight and the chances of broken wire connections. The disadvantage is the added cost of a microprocessor and FET switch matrix inside every battery system. However, in mass production, the method of **Fig. 5** will offer the most flexibility since less expensive connectors could be used, and faster charging times could be accomplished through “strobing” effects where multiple cells could be charged at the same time once they are matched to have the same capacity.  
175 Also the cost of the integrated circuit and FET matrix would drop rapidly as the volume of battery systems increase.

**Figs. 2, 4 and 5** illustrate the method and apparatus used to construct a flexible and extensible battery system for use in r/c model vehicles. All of the battery cells used in this invention are wired together using  
180 solder joints. Mechanical connection of r/c battery systems is not viable because of corrosion, dirt, and weight considerations. The dominant reason why battery systems need a soldered joint is that in car and model airplane applications, stresses of up to five times the acceleration of gravity can be placed on the